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Constraints on γ and Strong Phases from $B \to \pi K$ Decays

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Abstract

As we pointed out recently, the neutral decays $B_d \to \pi^{\mp}K^{\pm}$ and $B_d \to \pi^0 K$ may provide non-trivial bounds on the CKM angle γ. Here we reconsider this approach in the light of recent CLEO data, which look very interesting. In particular, the results for the corresponding CP-averaged branching ratios are in favour of strong constraints on γ, where the second quadrant is preferred. Such a situation would be in conflict with the standard analysis of the unitarity triangle. Moreover, constraints on a CP-conserving strong phase $\delta_{\rm n}$ are in favour of a negative value of $\cos\delta_{\rm n}$, which would be in conflict with the factorization expectation. In addition, there seems to be an interesting discrepancy with the bounds that are implied by the charged $B \to \pi K$ system: whereas these decays favour a range for γ that is similar to that of the neutral modes, they point towards a positive value of $\cos\delta_{\rm c}$, which would be in conflict with the expectation of equal signs for $\cos\delta_{\rm n}$ and $\cos\delta_{\rm c}$.

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CONSTRAINTS ON γ AND STRONG PHASES FROM $B \to \pi K$ DECAYS

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As we pointed out recently, the neutral decays $B_d \to \pi^\mp K^\pm$ and $B_d \to \pi^0 K$ may provide non-trivial bounds on the CKM angle γ. Here we reconsider this approach in the light of recent CLEO data, which look very interesting. In particular, the results for the corresponding CP-averaged branching ratios are in favour of strong constraints on γ, where the second quadrant is preferred. Such a situation would be in conflict with the standard analysis of the unitarity triangle. Moreover, constraints on a CP-conserving strong phase $\delta_{\rm n}$ are in favour of a negative value of $\cos\delta_{\rm n}$, which would be in conflict with the factorization expectation. In addition, there seems to be an interesting discrepancy with the bounds that are implied by the charged $B \to \pi K$ system: whereas these decays favour a range for γ that is similar to that of the neutral modes, they point towards a positive value of $\cos\delta_{\rm c}$, which would be in conflict with the expectation of equal signs for $\cos\delta_{\rm n}$ and $\cos\delta_{\rm c}$.

1 Introduction

In order to obtain direct information on the angle γ of the unitarity triangle of the CKM matrix, $B \to \pi K$ decays are very promising. In the following, we focus on our analysis Ref. 1, making use of the most recent CLEO data[2]. Because of the small ratio $|V_{us}V_{ub}^*/(V_{ts}V_{tb}^*)| \approx 0.02$, $B \to \pi K$ modes are dominated by QCD penguin topologies. Due to the large top-quark mass, we have also to care about electroweak (EW) penguins. In the case of $B_d^0 \to \pi^- K^+$ and $B^+ \to \pi^+ K^0$, these topologies contribute in colour-suppressed form and are hence expected to play a minor role, whereas they contribute in colour-allowed form to $B^+ \to \pi^0 K^+$ and $B_d^0 \to \pi^0 K^0$ and may here even compete with tree-diagram-like topologies.

So far, strategies to probe γ through $B \to \pi K$ decays have focused on the following two systems: $B_d \to \pi^\mp K^\pm$, $B^\pm \to \pi^\pm K$ ("mixed")[3,4], and $B^\pm \to \pi^0 K^\pm$, $B^\pm \to \pi^\pm K$ ("charged")[5]. Recently, we pointed out that also the neutral combination $B_d \to \pi^\mp K^\pm$, $B_d \to \pi^0 K$ is very promising[6].

2 Constraints on γ

Interestingly, already CP-averaged branching ratios may lead to highly non-trivial constraints on γ. Here the key quantities are

$$R \equiv \frac{\mathrm{BR}(B_d \to \pi^\mp K^\pm)}{\mathrm{BR}(B^\pm \to \pi^\pm K)} = 0.95 \pm 0.28 \quad (1)$$

$$R_{\rm c} \equiv \frac{2\mathrm{BR}(B^\pm \to \pi^0 K^\pm)}{\mathrm{BR}(B^\pm \to \pi^\pm K)} = 1.27 \pm 0.47 \quad (2)$$

$$R_{\rm n} \equiv \frac{\mathrm{BR}(B_d \to \pi^\mp K^\pm)}{2\mathrm{BR}(B_d \to \pi^0 K)} = 0.59 \pm 0.27, \quad (3)$$

where we have also taken into account the CLEO results reported in Ref. 2. If we employ the $SU(2)$ flavour symmetry and certain dynamical assumptions, concerning mainly the smallness of FSI effects, we may derive a general parametrization[6] for (1)–(3),

$$R_{\rm (c,n)} = R_{\rm (c,n)}(\gamma, q_{\rm (c,n)}, r_{\rm (c,n)}, \delta_{\rm (c,n)}), \quad (4)$$

where $q_{\rm (c,n)}$ denotes the ratio of EW penguins to "trees", $r_{\rm (c,n)}$ is the ratio of "trees" to QCD penguins, and $\delta_{\rm (c,n)}$ is the CP-conserving strong phase between "tree" and QCD penguin amplitudes. The parameters $q_{\rm (c,n)}$ can be fixed through theoretical arguments: in the "mixed" system, we have

$q \approx 0$, as EW penguins contribute only in colour-suppressed form; in the charged[5] and neutral[6] $B \to \pi K$ systems, $q_{\rm c}$ and $q_{\rm n}$ can be fixed through the $SU(3)$ flavour symmetry without dynamical assumptions. The $r_{\rm (c,n)}$ can be determined with the help of additional experimental information: in the "mixed" system, r can be fixed through arguments based on "factorization", whereas $r_{\rm c}$ and $r_{\rm n}$ can be determined from $B^+ \to \pi^+\pi^0$ by using only the $SU(3)$ flavour symmetry.

At this point, a comment on FSI effects is in order. Whereas the determination of q and r as sketched above may be affected by FSI effects, this is *not* the case for $q_{\rm c,n}$ and $r_{\rm c,n}$, since here $SU(3)$ suffices. Nevertheless, we have to assume that $B^+ \to \pi^+ K^0$ or $B^0_d \to \pi^0 K^0$ do *not* involve a CP-violating weak phase:

$$A(B^+ \to \pi^+ K^0) = -\,|\tilde{P}|e^{i\delta_{\tilde{P}}} = A(B^- \to \pi^- \overline{K^0}). \tag{5}$$

This relation may be affected by rescattering processes such as $B^+ \to \{\pi^0 K^+\} \to \pi^+ K^0$:

$$A(B^+ \to \pi^+ K^0) = -\,|\tilde{P}|e^{i\delta_{\tilde{P}}}\left[1 + \rho_{\rm c}\, e^{i\theta} e^{i\gamma}\right],$$

where $\rho_{\rm c}$ is doubly Cabibbo-suppressed and is naively expected to be negligibly small. In the "QCD factorization" approach[7], there is no significant enhancement of $\rho_{\rm c}$ through rescattering processes. However, there is still no theoretical consensus on the importance of FSI effects. In the charged $B \to \pi K$ strategy to probe γ, they can be taken into account through $SU(3)$ flavour-symmetry arguments and additional data on $B^\pm \to K^\pm K$ decays. The present experimental upper bounds on these modes are not in favour of dramatic effects. In the case of the neutral strategy, FSI effects can be included in an *exact manner* with the help of the mixing-induced CP asymmetry $\mathcal{A}_{\rm CP}^{\rm mix}(B_d \to \pi^0 K_{\rm S})$[6].

In contrast to $q_{\rm (c,n)}$ and $r_{\rm (c,n)}$, the strong phase $\delta_{\rm (c,n)}$ suffers from large hadronic uncertainties and is essentially unknown. However, we can get rid of $\delta_{\rm (c,n)}$ by keeping it as a "free" variable, yielding minimal and maximal values for $R_{\rm (c,n)}$:

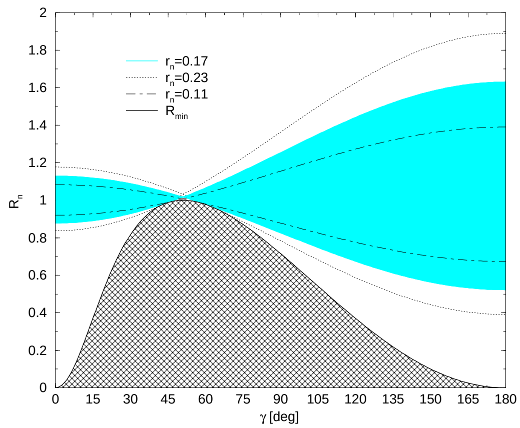

Figure 1. The dependence of the extremal values of $R_{\rm n}$ (neutral $B \to \pi K$ system) on γ for $q_{\rm n} = 0.63$.

$$\left. R^{\rm ext}_{\rm (c,n)}\right|_{\delta_{\rm (c,n)}} = \mbox{function}(\gamma, q_{\rm (c,n)}, r_{\rm (c,n)}). \tag{6}$$

Keeping in addition $r_{\rm (c,n)}$ as a free variable, we obtain another – less restrictive – minimal value for $R_{\rm (c,n)}$:

$$\left. R^{\rm min}_{\rm (c,n)}\right|_{r_{\rm (c,n)},\delta_{\rm (c,n)}} = \kappa(\gamma, q_{\rm (c,n)}) \sin^2\gamma. \tag{7}$$

In Fig. 1, we show the dependence of (6) and (7) on γ for the neutral $B \to \pi K$ system[a]. Here the crossed region below the $R_{\rm min}$ curve, which is described by (7), is excluded. On the other hand, the shaded region is the allowed range (6) for $R_{\rm n}$, arising in the case of $r_{\rm n} = 0.17$. Fig. 1 allows us to read off immediately the allowed region for γ for a given value of $R_{\rm n}$. Using the central value of the present CLEO result (3), $R_{\rm n} = 0.6$, the $R_{\rm min}$ curve implies $0^\circ \leq \gamma \leq 21^\circ \vee 100^\circ \leq \gamma \leq 180^\circ$. The corresponding situation in the $\overline{\varrho}$–$\overline{\eta}$ plane is shown in Fig. 2, where the crossed region is excluded and the circles correspond to $R_b = 0.41 \pm 0.07$. As the theoretical expression for $q_{\rm n}$ is proportional to $1/R_b$, the constraints in the $\overline{\varrho}$–$\overline{\eta}$ plane are actually more appropriate than the constraints on γ.

[a] The charged $B \to \pi K$ curves look very similar.

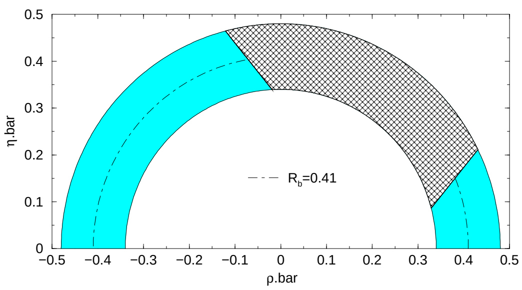

Figure 2. The constraints in the $\overline{\varrho}$–$\overline{\eta}$ plane implied by (7) for $R_{\rm n} = 0.6$ and $q_{\rm n} = 0.63 \times [0.41/R_b]$.

If we use additional information on the parameter $r_{\rm n}$, we may put even stronger constraints on γ. For $r_{\rm n} = 0.17$, we obtain, for instance, the allowed range $138^\circ \leq \gamma \leq 180^\circ$. It is interesting to note that the $R_{\rm min}$ curve is only effective for $R_{\rm n} < 1$, which is favoured by the most recent CLEO data[2]. A similar pattern is also exhibited by the first BELLE results[8] presented at this conference, yielding $R_{\rm n} = 0.4 \pm 0.2$.

For the central value $R_{\rm c} = 1.3$ of (2), (7) is not effective and $r_{\rm c}$ has to be fixed in order to constrain γ. Using $r_{\rm c} = 0.21$, we obtain $87^\circ \leq \gamma \leq 180^\circ$. Although it is too early to draw definite conclusions, it is important to emphasize that the most recent CLEO results on $R_{\rm (c,n)}$ prefer the second quadrant for γ, i.e. $\gamma \geq 90^\circ$. Similar conclusions were also obtained using other $B \to \pi K$, $\pi\pi$ strategies[9]. Interestingly, such a situation would be in conflict with the standard analysis of the unitarity triangle[10], yielding $38^\circ \leq \gamma \leq 81^\circ$.

3 Constraints on Strong Phases

The $R_{\rm (c,n)}$ allow us to determine $\cos\delta_{\rm (c,n)}$ as functions of γ, thereby providing also constraints on the strong phases $\delta_{\rm (c,n)}$[1]. Interestingly, the present CLEO data are in favour of $\cos\delta_{\rm n} < 0$, which would be in conflict with "factorization". Moreover, they point towards a positive value of $\cos\delta_{\rm c}$, which would be in conflict with the theoretical expectation of equal signs for $\cos\delta_{\rm c}$ and $\cos\delta_{\rm n}$.

4 Conclusions and Outlook

If future data should confirm the "puzzling" situation for γ and $\cos\delta_{\rm c,n}$ favoured by the present $B \to \pi K$ CLEO data, it may be an indication for new-physics contributions to the EW penguin sector, or a manifestation of flavour-symmetry-breaking effects. In order to distinguish between these possibilities, further studies are needed. As soon as CP asymmetries in $B_d \to \pi^\mp K^\pm$ or $B^\pm \to \pi^0 K^\pm$ are observed, we may even *determine* γ and $\delta_{\rm (c,n)}$. Here we may also arrive at a situation, where the $B \to \pi K$ observables do not provide any solution for these quatities[11], which would be an immediate indication for new physics. We look forward to new data from the B-factories.

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